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# DAWN Mission Bus and Waveguide Venting Analysis Review

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|---|--|--------------------------------|---------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b>    |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br><b>1 of 36</b> |

# **DAWN Mission Bus and Waveguide Venting Analysis Review**


**May 24, 2007**

|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>2 of 36     |

## Approval and Document Revision History

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| Approved: _____ | Original signed on file<br>_____<br>NESC Director | 6-4-07<br>_____<br>Date |
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|   |  |                                |                           |
|---|--|--------------------------------|---------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b>    |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br><b>3 of 36</b> |

## Table of Contents

### Volume I: Consultation Report

|             |  |           |
|-------------|--|-----------|
| <b>1.0</b>  | <b>Authorization and Notification.....</b>                     | <b>5</b>  |
| <b>2.0</b>  | <b>Signature Page.....</b>                                     | <b>6</b>  |
| <b>3.0</b>  | <b>List of Team Members.....</b>                               | <b>7</b>  |
| <b>4.0</b>  | <b>Executive Summary .....</b>                                 | <b>8</b>  |
| <b>5.0</b>  | <b>Assessment Plan .....</b>                                   | <b>9</b>  |
| <b>6.0</b>  | <b>Description of the Problem and Proposed Solutions .....</b> | <b>9</b>  |
| 6.1         | Description of Problem .....                                   | 9         |
| <b>7.0</b>  | <b>Data Analysis.....</b>                                      | <b>10</b> |
| 7.1         | Corona Breakdown .....   | 12        |
| 7.2         | Multipactor.....   | 17        |
| 7.3         | JPL's Bus and Waveguide Venting Analysis Assumptions .....     | 17        |
| 7.4         | Venting Analysis.....  | 18        |
| 7.5         | Materials Outgassing Considerations .....                      | 24        |
| 7.5.1       | Materials TDT contribution to DAWN Outgassing Concerns .....   | 24        |
| <b>8.0</b>  | <b>Findings, Observations, and Recommendations .....</b>       | <b>27</b> |
| 8.1         | Findings.....  | 27        |
| 8.2         | Observations .....   | 27        |
| 8.3         | Recommendations.....   | 27        |
| <b>9.0</b>  | <b>Alternate Viewpoints .....</b>                              | <b>28</b> |
| <b>10.0</b> | <b>Other Deliverables .....</b>                                | <b>28</b> |
| <b>11.0</b> | <b>Lessons Learned.....</b>                                    | <b>28</b> |
| <b>12.0</b> | <b>Definition of Terms .....</b>                               | <b>29</b> |
| <b>13.0</b> | <b>List of Acronyms .....</b>                                  | <b>31</b> |
| <b>14.0</b> | <b>References.....</b>   | <b>31</b> |
|             | <b>Volume II: Appendices .....</b>                             | <b>33</b> |

|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>4 of 36     |

## Volume II: Appendices

|   |    |
|---|----|
| Appendix A. NESC Request Form NESC-PR-003-FM-01 ..... | 34 |
|---|----|


### List of Figures

|   |    |
|---|----|
| Figure 7.1-1. Breakdown Voltage vs. Pressure [ref. 2] .....                                       | 12 |
| Figure 7.1-2. Margin Factor of Pressure.....  | 13 |
| Figure 7.1-3. Block Diagram of the DAWN Telecom Subsystem [ref. 4] .....                          | 14 |
| Figure 7.1-4. +Y and +X Panel Internal View .....   | 15 |
| Figure 7.1-5. +X Panel External View [ref. 4] .....   | 16 |
| Figure 7.4-1. DAWN Spacecraft Bust Configuration for Venting Analysis,<br>Side View [ref. 5]..... | 19 |
| Figure 7.4-2. DAWN Spacecraft Bus Configuration for Venting Analysis, Top View [ref. 5] .....     | 20 |
| Figure 7.4-3. DAWN Altitude During Launch.....  | 20 |
| Figure 7.4-4. DAWN Bus External (Approximately Internal) Pressure Profile.....                    | 21 |
| Figure 7.4-5. Diplexer and Isolator Internal Pressure Profile.....                                | 22 |

### List of Tables

|  |    |
|--|----|
| Table 7.4-1. Gas Temperatures at Different Pumpdown Pressure and<br>Temperatures Assuming Adiabatic Expansion .....          | 23 |
| Table 7.4-2. Pumpdown Time Required if Adiabatic Expansion Temperature is Assumed in<br>Molecular Vent Flow Calculation..... | 24 |




|   |  |                                |                           |
|---|--|--------------------------------|---------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b>    |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br><b>5 of 36</b> |

## Volume I: Assessment Report

### 1.0 Authorization and Notification

An independent real-time assessment of DAWN Mission bus and waveguide venting analysis was requested on May 2, 2007 by Mr. R. Lloyd Keith, NESC Chief Engineer of the Jet Propulsion Laboratory (JPL). The request was approved by the NESC Review Board (NRB) on May 3, 2007 and assigned to the Lead for Power and Avionics, Mr. Mitchell Davis. Subsequently, the lead was reassigned to Power and Avionics Technical Discipline Team (TDT) member, Mr. Bob Kichak, with assistance from NESC Principal Engineer, Mr. Clint Cragg. The team was tasked to perform an independent review of JPL bus and waveguide venting analysis for the DAWN Mission, and verify assumptions, calculations, and conclusions. At the time of task inception, the spacecraft was at the launch site with launch scheduled by the end of June, 2007.

|   |  |                                |                           |
|---|--|--------------------------------|---------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b>    |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br><b>6 of 36</b> |

## 2.0 Signature Page

Team signature on file 07/30/07

\_\_\_\_\_  
Mr. Robert Kichak (Lead)                      Date

\_\_\_\_\_  
Mr. Clinton Cragg (Co-Lead)                      Date


\_\_\_\_\_  
Dr. James Sutter                      Date

\_\_\_\_\_  
Mr. Donald Holder                      Date

\_\_\_\_\_  
Mr. Frank Jeng                      Date


\_\_\_\_\_  
Mr. Arthur Ruitberg                      Date

\_\_\_\_\_  
Dr. Victor Sank                      Date

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|---|--|--------------------------------|---------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b>    |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br><b>7 of 36</b> |

### 3.0 List of Team Members

| Name               | Position/TDT Affiliation                                    | Center/Contractor            |
|--------------------|---|------------------------------|
| <b>Core Team</b>   |   |                              |
| Robert Kichak      | Lead, Power & Avionics TDT                                  | GSFC/MEI Technologies        |
| Clinton Cragg      | Co-Lead, NESC Principal Engineer                            | LaRC                         |
| Roy Savage         | Program Analyst   | LaRC                         |
| Donald Holder      | Venting   | MSFC                         |
| Frank Jeng         | Venting   | JSC/Jacobs                   |
| Arthur Ruitberg    | High Voltage  | GSFC/Space Power Electronics |
| Victor Sank        | RF Systems  | GSFC/MEI Technologies        |
| James Sutter       | Materials   | GRC                          |
| <b>Consultants</b> |   |                              |
| Mitchell Davis     | NESC, Power and Avionics<br>Technical Fellow                | GSFC                         |
| Robert Piascik     | NESC, Materials Technical Fellow                            | LaRC                         |
| Henry Rotter       | NESC, Fluids, Life Support, and<br>Thermal Technical Fellow | JSC                          |
| R. Lloyd Keith     | NESC, Chief Engineer for JPL                                | JPL                          |
| <b>Support</b>     |   |                              |
| Christina Cooper   | Technical Writer  | LaRC, Swales Aerospace       |
| Pamela Sparks      | Project Coordinator   | LaRC, Swales Aerospace       |

|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>8 of 36     |


## 4.0 Executive Summary

A concern was raised regarding the time after launch when the DAWN Mission Communications Subsystem, which contains a 100 Watt X-Band Traveling Wave Tube Amplifier (TWTA) with a high voltage ((approximately 7 Kilo Volt (KV)) Electronic Power Converter (EPC), will be powered on for the first post-launch downlink. This activation is planned to be approximately one hour after launch. Orbital Sciences (the DAWN Mission spacecraft contractor) typically requires a 24-hour wait period prior to high voltage initiation for Earth-orbiting Science and GEO spacecraft. The concern relates to the issue of corona and/or radio frequency (RF) breakdown of the TWTA ((high voltage direct current (DC) and RF)), and of the microwave components (high voltage RF) in the presence of partial atmospheric pressures or outgassing constituents. In particular, generally the diplexer and circulator are susceptible to RF breakdown in the corona region due to the presence of small physical gaps ((~ 2.5 millimeter (mm)) between conductors that carry an RF voltage.

The DAWN spacecraft has no low power RF system option. The Jet Propulsion Laboratory (JPL) design rules [ref. 1] require spacecraft telemetry status verification. Prior practice for similar JPL deep space missions is to energize the TWTA within approximately one hour after launch. The DAWN Mission performed venting analyses that concluded that the TWTA can be activated within a very short time after separation from the launch vehicle. Also, the TWTA was tested at the component level in the corona region, and is specified to operate without damage or degradation at any pressure between 760 Torr (ambient pressure) and hard vacuum (deep space). The primary issue is to understand when it is safe (from a mission success standpoint) to operate the Telecom Subsystem after launch. Should breakdown occur, permanent damage to the hardware could result. If the primary TWTA fails, fault detection software may power the redundant TWTA to the same pressure environment and potential for a common cause failure.

The request is for a real-time independent review of the DAWN Mission waveguide venting analysis to verify the assumptions, limitations, and calculations. Preliminary findings, observations, and recommendations were requested by May 11, 2007 and a final report by May 25, 2007. At the start of the review, the DAWN spacecraft was at the launch site, with launch scheduled before the end of June 2007.

The NESC concurred the DAWN Mission communication system is safe for activation consistent with JPL's planned turn-on of 55 minutes or longer after launch. This concurrence was contingent on four recommendations to be accomplished by the DAWN Mission team prior to launch that include, verifying the vent holes in the diplexer, wave guide near the diplexer are clear of blockage, review of the venting analysis to ensure the gas temperature assumption of 298 °K is valid, review the as-built configuration for any changes that could affect the offgassing

|   |  |                                |                           |
|---|--|--------------------------------|---------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b>    |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br><b>9 of 36</b> |

analysis, and confirm the composition and pore size of the Spectra Mesh<sup>®</sup> filters to ensure that water droplets will pass through freely.

## 5.0 Assessment Plan

The request was for a real-time independent review of the DAWN Mission waveguide venting analysis assumptions and calculations performed by JPL (information provided by Lloyd Keith on May 2, 2007). The issue related to the amount of time after launch that is needed to wait before the Traveling Wave Tube Assembly (TWTA) can be powered on without the threat of high voltage/RF breakdown and possible corona damage due to remnant partial atmospheric pressures or outgassing constituents. An NESC Team was formed co-chaired by Bob Kichak, member of the Power and Avionics Technical Discipline Team (TDT) and Clint Cragg, NESC Principal Engineer. Technical disciplines represented on the NESC Team included high voltage expertise, materials, gas transport/venting analysis, and RF systems. Preliminary findings, observations, and recommendations were requested by May 11, 2007 and a final report by May 25, 2007 to support the DAWN Mission launch scheduled for June, 2007. The NESC Team held technical interchange meetings and reviewed materials provided by JPL and the spacecraft contractor, Orbital Sciences Corporation (OSC).


## 6.0 Description of the Problem and Proposed Solutions

### 6.1 Description of Problem

The DAWN spacecraft is built by OSC, JPL manages the project, which is due to launch at end of June, 2007. From the DAWN Mission's website:

“DAWN's goal is to characterize the conditions and processes of the solar system's earliest epoch by investigating in detail two of the largest protoplanets remaining intact since their formations. Ceres and Vesta reside in the extensive zone between Mars and Jupiter together with many other smaller bodies, called the asteroid belt. Each has followed a very different evolutionary path constrained by the diversity of processes that operated during the first few million years of solar system evolution.”

Due to the mission profile of this spacecraft, JPL desires that communications be established approximately one hour after launch in order to monitor critical functions. Concerns were raised by OSC personnel that corona and/or RF breakdown of the TWTA (high voltage DC) and of the microwave components (high voltage RF) may occur if partial pressures or outgas constituents are present. Particular concern was directed to the diplexer and circulator which are susceptible to RF breakdown because of their generally small physical gaps (~ 2.5 mm) that carry an RF

|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>10 of 36    |

voltage. The overriding issue was to understand when it would be safe to operate the Telecom Subsystem after launch.


Gani Ganapathi of JPL's Thermal and Cryogenic Engineering Section, at the request of the Dawn Project, has conducted extensive analysis on this issue. Based on the results of this analysis, the DAWN Project came to the conclusion that energizing the Telecom subsystem at the one hour point can occur without damage. However, OSC has maintained that waiting the customary 24 hours is required to ensure the subsystem's safety. In lieu of this, OSC has requested the fault protection software that can switch the redundant communications subsystem in the event of primary failure be delayed in activation. The NESC was asked to review JPL's analysis and ascertain its veracity.

## 7.0 Data Analysis

The JPL DAWN venting analysis review by the NESC team was precipitated by concerns expressed by James Brown (retired) and Joseph Whitacre (Chief Engineer) of OSC, who asserted it was necessary to wait at least 24 hours after launch before energizing the DAWN spacecraft's 100 Watt TWTA. This is OSC's common procedure for near Earth missions. Typically, near Earth missions have a low power S-band system for spacecraft housekeeping telemetry in addition to high power X, Ku, or Ka-band systems for high data rate payloads. With such near Earth missions, it is also common to wait days before activating instruments that use high voltages.

The DAWN spacecraft supports a deep space mission with only an X-band communication system compatible with the Deep Space Network (DSN). It is typical for this kind of mission to have only the X-band system and it is common for it to get energized at approximately one hour after launch. Examples are Deep Impact (DI), Solar TERrestrial RELations Observatory (STEREO), Messenger, MRO (Mars Orbiter), and Mars Lander. The MRO has a TWTA system with a similar power rating (100 Watts) as the DAWN spacecraft while the STEREO and DI TWTA's having lower capacities (60 Watts). Since there is no low power (S-band or other) communication system on these spacecraft, receiving housekeeping telemetry requires early (~ 1 hour) activation of the X-band system following launch. The requirements of spacecraft risk management are satisfied by designing the communications system so that it is safe to energize the X-band TWTA approximately one hour after launch. None of the other identified missions have encountered a problem with power activation following launch.

The concern raised by Mr. Joe Whitacre is that corona discharge could damage RF components. The initial concern was that should the prime TWTA fail, the fault detection software could detect the failure and turn the redundant TWTA on, thereby exposing the backup system to a common cause failure. Mr. Whitaker requested a 24 hour delay in the enable of fault protection

|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br>11 of 36    |


software to minimize corona discharge risks. Dr. Marc Rayman, the DAWN Chief Engineer at JPL, decided that the primary issue was not the risk to the redundant communications system, but what is the confidence of the 2004 venting analysis and was it safe to activate the prime TWTA. There was no engineering analysis presented to the NESC Team support a 24 hour wait period prior to energizing DAWN's communication system. If viable, the practice of waiting before turn-on of high power RF or high voltage systems provides additional risk mitigation against unknowns. However, for the DAWN mission such a long period without telemetry would jeopardize mission success. It was not within the charter of the NESC Team to comment regarding the fault protection software implementation.

All RF components were tested in hard vacuum (less than  $10^{-5}$  Torr) during development and passed space qualification testing. The likely components to experience corona breakdown problems are the TWTA, the isolator (circulator), and the diplexer. All RF components in high voltage systems need to be considered, but generally only components with small physical gaps ( $\sim 2.5$  mm) where high voltages are concentrated will be susceptible to breakdown. The TWTA has had some level of testing during vacuum testing and then during return to ambient pressure and is believed to not be the component of main concern. The DAWN Mission diplexer design is different from the S-band and X-band diplexers commonly used by near Earth missions. Rather than using coaxial resonant cavities that have small gaps and high voltages, the DAWN Mission diplexer uses a waveguide beyond cutoff as its transmit portion. The design eliminates voltage multiplication and small gaps that are commonly found in diplexers. This leaves the isolator (circulator) as the component of highest concern.

There are two different kinds of RF breakdown that RF components must be tested for:

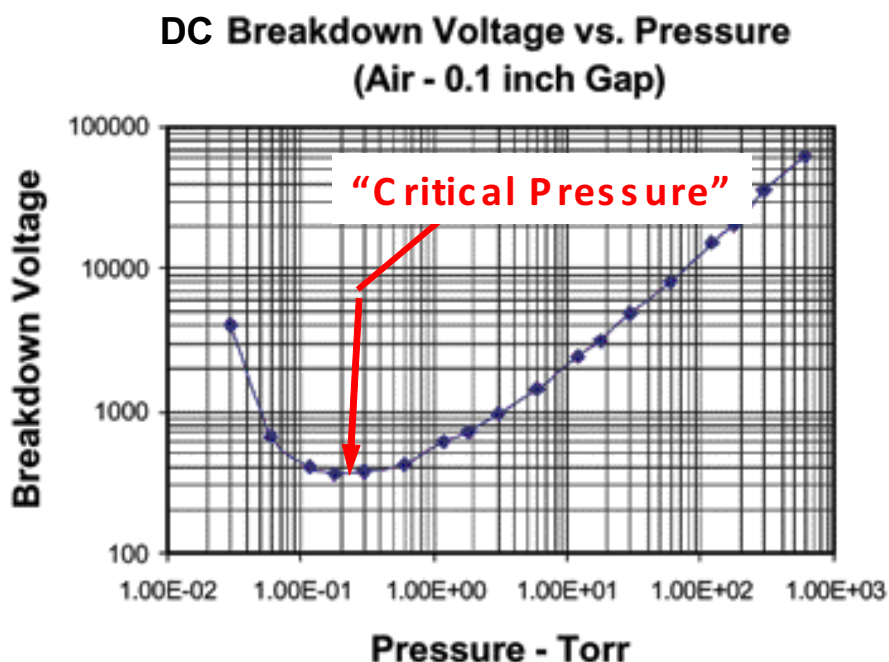
- a. Corona is the ionization of low density gas ( $\sim 0.1$  to 10 Torr) caused by a voltage high enough to pull electrons from an atom. As the ions accelerate in the electric field, they collide with other atoms, causing more gas ionization. The resultant current flow can destroy the device. Corona does not occur in hard vacuum (less than  $10^{-5}$  Torr) as the number of atoms per unit volume is too low to result in significant ionization and a significant current.
- b. Multipactor is an electron resonant effect that occurs in hard vacuum where high voltage ( $> \sim 18$  volts) accelerates electrons across a small gap to a high enough velocity so that they produce secondary electrons when they strike the material surface. If the RF frequency is such that the voltage reverses just as the secondary electrons are formed they then accelerate to the other side of the gap and cause tertiary electrons, and the process cascades. In less than a millisecond, a high current can develop and the device can be destroyed.



|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br>12 of 36    |

## 7.1 Corona Breakdown


F. Paschen created the “Paschen Curve” in 1889, which describes the relationship between gap distance, pressure and voltage during ionization or breakdown processes. The “Critical Pressure” is the “point” in the Paschen Curve at which the breakdown voltage of a given geometry is a minimum. Typically this occurs at a pressure between 0.1 and 10 Torr. The “Critical Pressure Region” is the range of pressures that will allow breakdown to occur given an appropriate set of conditions (voltage, frequency, gap distance, etc). The Breakdown Voltage and Pressure can be seen in Figure 7.1-1.



**Figure 7.1-1. Breakdown Voltage vs. Pressure [ref. 2]**

A review of JPL Technical Report 32-1500 (1970) by R. Woo [ref. 3] indicates that the “Critical Pressure” for RF breakdown is about  $10^1$  Torr. All of the publications and literature on RF breakdown show “Critical Pressure” to be in the 0.1 to 10 Torr region. This suggests a susceptible component one can operate at pressures below the “Critical Pressure” and maintain a margin to corona (move left on the curve) since outgassing constituents (i.e.: easily ionizable electrons) move the curve up or down but not right or left. The DAWN Mission team concluded  $10^{-2}$  Torr is a reasonable upper pressure to operate RF components. This provides from  $10^1$  to  $10^3$  margin factor on pressure and an improvement of greater than 6 dB margin on voltage



|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br>13 of 36    |

breakdown as shown in Figure 7.1-2. The breakdown voltage margin will increase further over time as the bus and waveguides continue to vent and the local pressures are less than the “Critical Pressure”.

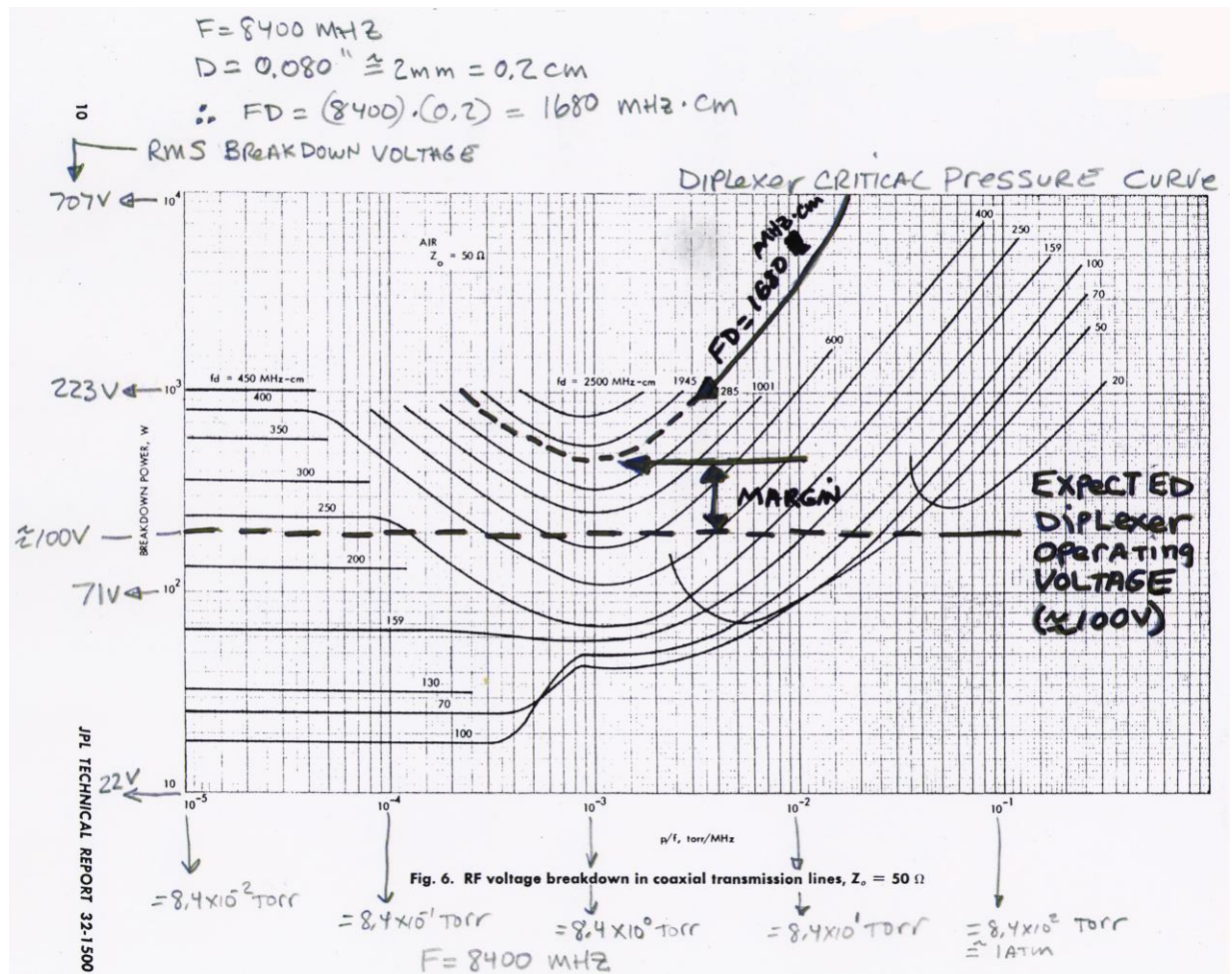

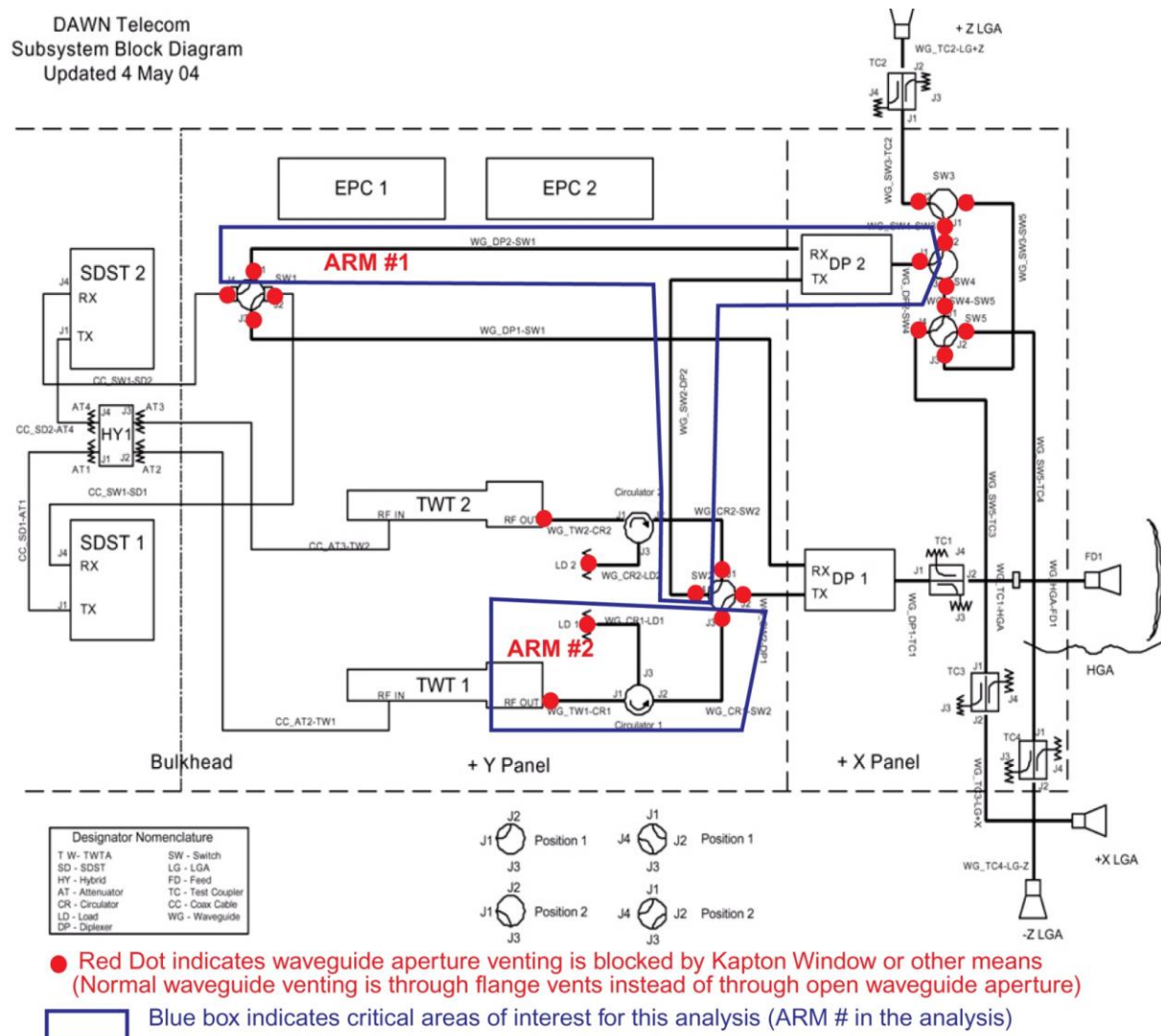


Figure 7.1-2. Margin Factor of Pressure [ref. 2]


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|---|--|--------------------------------|----------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b>     |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br><b>14 of 36</b> |

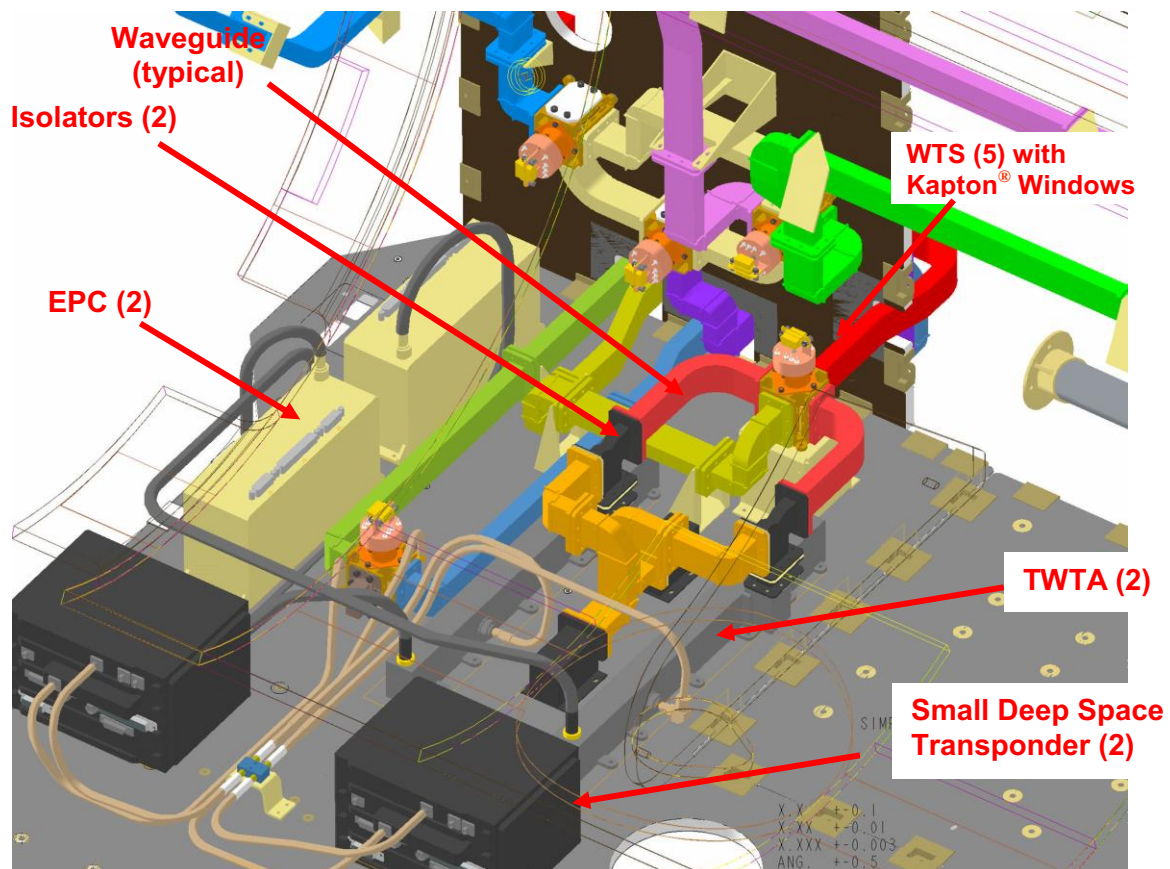
A block diagram of the DAWN spacecraft Telecom Subsystem is shown in Figure 7.1-3.




**Figure 7.1-3. Block Diagram of the DAWN Telecom Subsystem [ref. 4]**

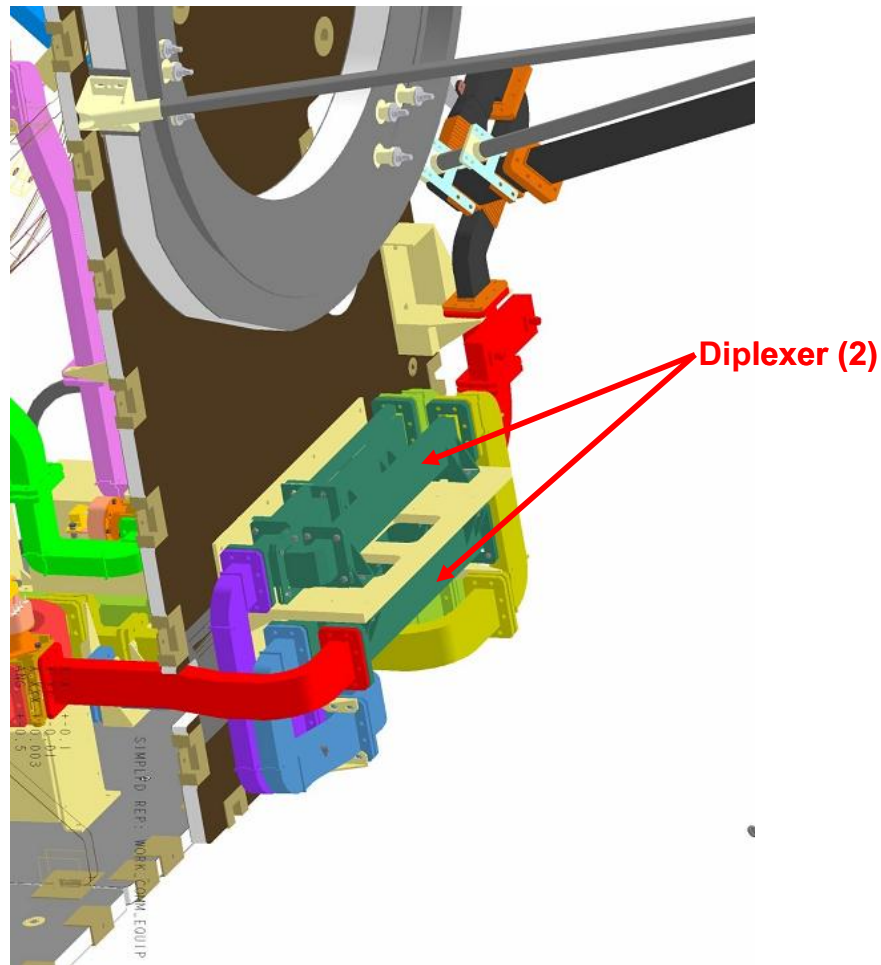
The major RF components discussed in the analyses are identified in Figures 7.1-4 and 7.1-5.

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|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br>15 of 36    |




**Figure 7.1-4. +Y and +X Panel Internal View [ref. 4]**

|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br>16 of 36    |



**Figure 7.1-5. +X Panel External View [ref. 4]**



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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>17 of 36    |

Concern -- TWTA Corona Test Conditions: Although the TWTA was powered on energized during both pump down, vacuum, and return to ambient pressure during thermal vacuum (TV) testing, TWTA only had the signal drive active on during the return to ambient pressure of the test.

## 7.2 Multipactor (Diplexer Design Analysis)


Generally the place of concern for multipactor in a diplexer is the transmit portion. Due to the design of the transmit portion of the DAWN diplexer, which uses a waveguide beyond cut off, the element in the receive portion of diplexer that is closest to the common point (antenna port) is the next most likely place susceptible to multipactor. Since the waveguide attenuation of the transmit signal at the receive frequency is about 90 to 100 dB, the power at that point is only - 70 dBW, which is far below the level where multipactor can occur.

Concern -- Multipactor Pulsed Power Testing: Even though the DAWN spacecraft diplexer was tested to 500 Watts, it was not continuous, but was pulsed with a 25 percent duty cycle. This testing was at or below  $10^{-5}$  Torr which is the multipactor region, not the corona region. Proper testing for multipactor requires pressure at or below  $10^{-5}$  Torr and continuous RF power for at least 12 hours.

## 7.3 JPL's Bus and Waveguide Venting Analysis Assumptions

JPL's bus and waveguide venting analysis assumptions include the following:

- The local component pressure profile is driven by the global launch profile.
- Entire bus volume is vented by only the 4, 7.62 centimeter (cm) vent holes.
- Vent holes are covered by Spectra Mesh<sup>®</sup> filter with 30 percent open area.
- The assumed vent path is only through the vent holes in the waveguide flanges.
- Gross bus dimensions were extracted from the OSC bus drawings.
- Waveguide, diplexer, and isolator dimensions and venting configurations are extracted from Critical Design Review packages and draft fabrication drawings.
- Waveguide transfer switches prevent venting through waveguide ports due to Kapton<sup>®</sup> windows. This means the diplexer and isolator are effectively isolated systems.
- Thermal blanket contributions to venting impedance is negligible (affects Diplexer venting).


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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>18 of 36    |

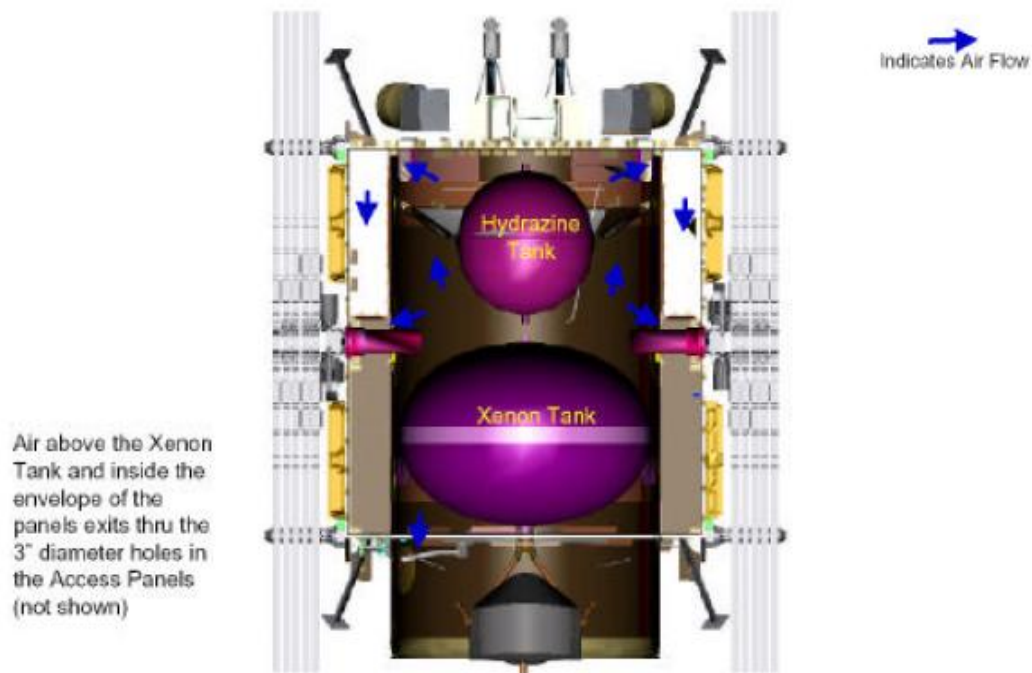
- i. Target internal bus pressure of  $10^{-3}$  Torr and internal waveguide pressure at Isolator and Diplexer of  $10^{-2}$  Torr.

However, the team believes that a simpler and conservative analysis can be done by assuming hard external vacuum five minutes after launch.

## 7.4 Venting Analysis


The DAWN venting analysis was performed by Gani Ganapathi of JPL [ref. 5, 6, and 7]. The analysis considered the DAWN Bus (a sketch of the spacecraft bus configuration is shown in Figures 7.4-1 and 7.4-2) and RF component venting. The target pressure for safe communications equipment activation, based on the corona discussion in the previous section, is  $10^{-2}$  for the RF component internal pressure and  $10^{-3}$  for the spacecraft bus. The interior portion of the spacecraft is a cylindrical structure that is vented to an outer box structure, which in turn is vented to space through 4, 7.62 cm vent holes. These are covered by thermal blankets with Spectra Mesh<sup>®</sup> filter material applied over cutouts. Based on the analysis below, it can be seen that the pressure exterior to the satellite is less than  $10^{-5}$  Torr approximately five minutes after launch.

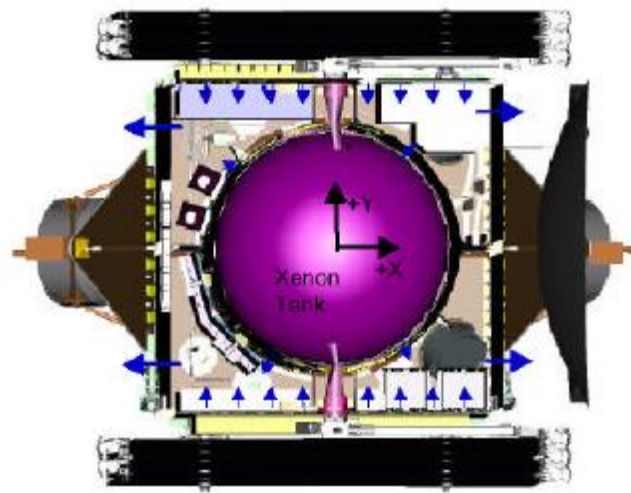
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|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br>19 of 36    |



**Figure 7.4-1. DAWN Spacecraft Bust Configuration for Venting Analysis, Side View [ref. 5]**

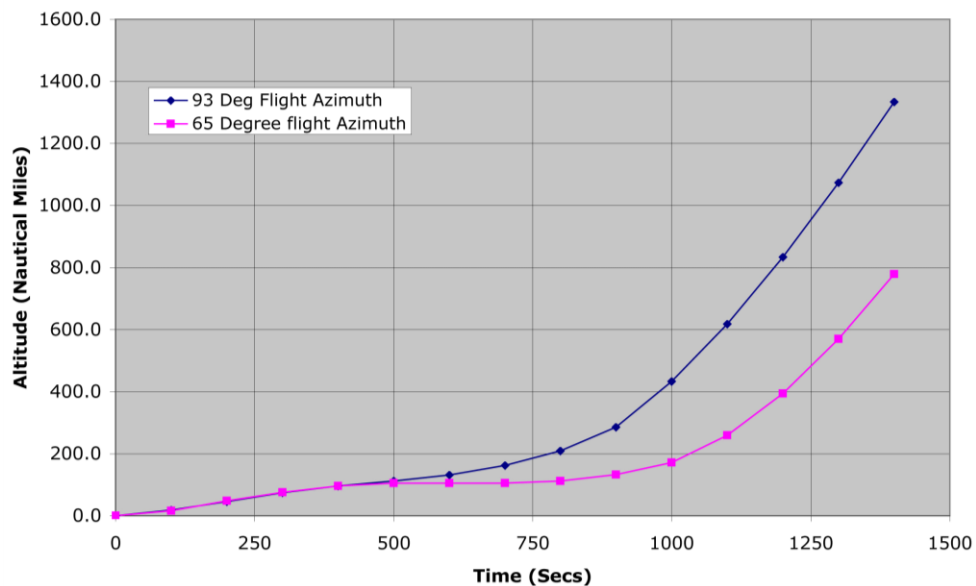
The driving function for the bus pressure is the Delta II ascent profile. This was analyzed by JPL and is shown in Figure 7.4-3..

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|---|--|--------------------------------|----------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b>     |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br><b>20 of 36</b> |




View is out through the S/C looking aft

**Figure 7.4-2. DAWN Spacecraft Bus Configuration for Venting Analysis, Top View [ref. 5]**

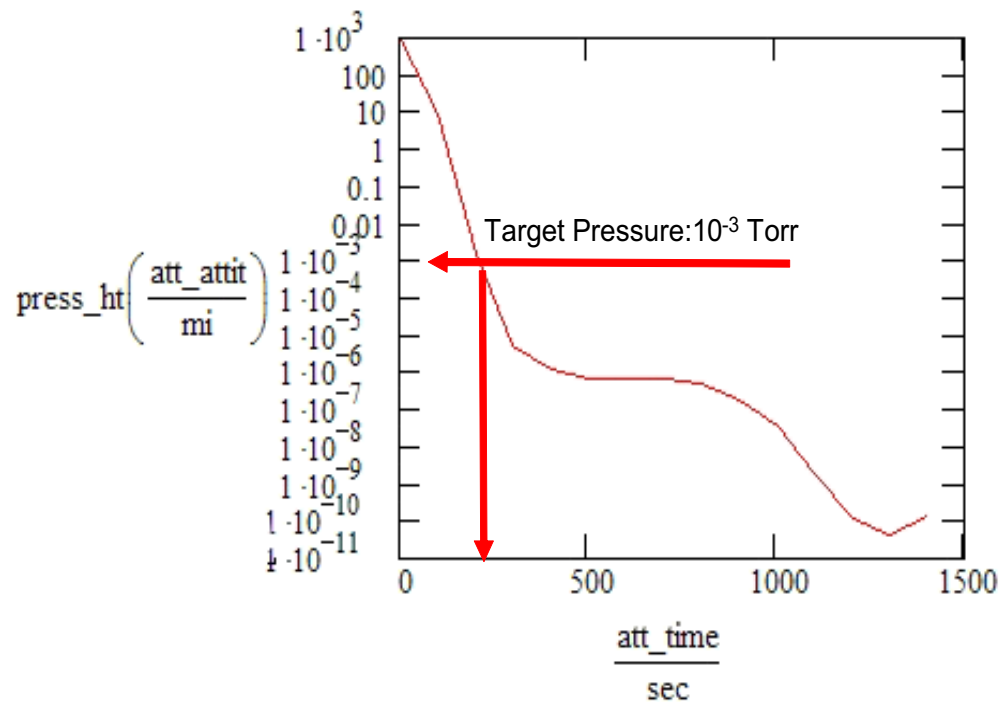


**Figure 7.4-3. DAWN Altitude During Launch [ref. 4]**




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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br>21 of 36    |

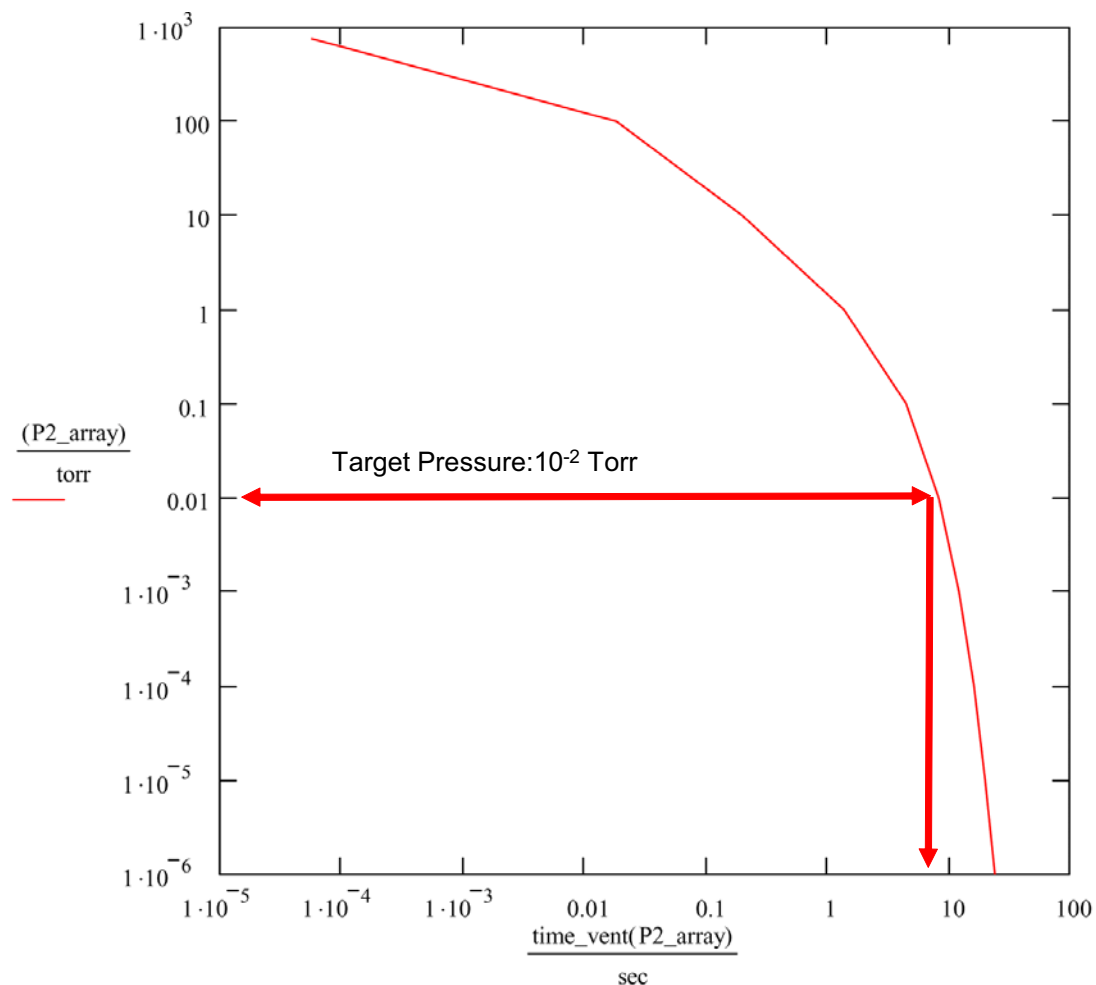
The resultant bus pressure profile from JPL's analysis is shown in Figure 7.4-4.



**Figure 7.4-4. DAWN Bus External (Approximately Internal) Pressure Profile [ref. 4]**

The diplexer and isolator internal pressure profile from JPL's analysis is shown in Figure 7.4-5.

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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br>22 of 36    |




**Figure 7.4-5. Diplexer and Isolator Internal Pressure Profile** [ref. 4]

There are two separate analyses that are considered:

- Venting of the spacecraft body to the vacuum of space.
- Venting of the waveguide to the spacecraft body.

Both of the venting analyses appear correct from atmospheric pressure down to about  $10^{-2}$  or  $10^{-3}$  Torr;  $10^{-2}$  Torr is all that is required for safe activation of the TWTA. It is not clear if the analysis below  $10^{-3}$  Torr, in particular in the neighborhood of  $10^{-5}$  Torr, inside the waveguide is correct since outgassing in a body with small vent holes can require days to complete. This is not a factor for this analysis due to the requirement of  $10^{-2}$  Torr, but curves showing pressures of  $10^{-5}$  Torr and below can cause confusion.

|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>23 of 36    |

As the Delta II rocket ascends and the ambient pressure decreases, so does the pressure inside the box and the bus, as a result of the 4, 7.62 cm vent hole design. It is assumed that the gas vent flow is relatively fast so that heat transfer between gas molecules and its environment can be neglected, an adiabatic expansion process.

Gas temperature drops in adiabatic processes can be described by the following thermodynamic equation:

$$(T_2/T_1) = (P_2/P_1)^{((\gamma-1)/\gamma)}$$

where:  $\gamma$  is specific heat ratio,  
T is absolute temperature, and  
P is pressure.


This is the same effect as air temperature at high altitude, which is very low. Temperature drops to almost absolute zero in deep space. As the gas temperature drops, so will be its molecular velocity. The NESC Team made an estimation of air and moisture temperature and mean molecular velocity in the TWTB box as a function of pressure as follows, assuming majority of the gas is air.

The NESC Team calculated pumpdown (vent) time for the bus and waveguide with an assumption that the gas temperature is actually the temperature that underwent adiabatic expansion, based on the time originally calculated by JPL.

The following table shows gas temperatures at different pumpdown pressures and temperatures assuming adiabatic expansion.

**Table 7.4-1. Gas Temperatures at Different Pumpdown Pressure and Temperatures Assuming Adiabatic Expansion**

| Pressure,<br>Torr | Temperature,<br>°K | Molecular<br>velocity,<br>cm/sec | Relative<br>velocity |
|-------------------|--------------------|----------------------------------|----------------------|
| 760               | 298.0              | 50.42                            | 1.00                 |
| 20                | 105.4              | 29.99                            | 0.59                 |
| 3                 | 61.3               | 22.87                            | 0.45                 |
| 1                 | 44.8               | 19.55                            | 0.39                 |
| 0.01              | 12.0               | 10.12                            | 0.20                 |
| 2.00E-05          | 2.0                | 4.17                             | 0.08                 |
| 1.00E-05          | 1.7                | 3.77                             | 0.07                 |

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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  |                                | Page #:<br>24 of 36    |

The following table shows pumpdown time required if the adiabatic expansion temperature is assumed in the molecular vent flow calculation. The adjusted times were based on JPL's original numbers scaled up as result of slower mean molecular velocity.

**Table 7.4-2. Pumpdown Time Required if Adiabatic Expansion Temperature is Assumed in Molecular Vent Flow Calculation**

| Pressure<br>P <sub>1</sub> , Torr | Pressure<br>P <sub>2</sub> , Torr | Temp. in<br>JPL calc.,<br>°K | Temp. if<br>adiabatic<br>expansion,<br>°K | Time JPL<br>calculated<br>from P1 to<br>P2, sec. | Time JPL<br>adjusted for<br>adiabatic<br>expansion,<br>sec. | Relative<br>molecular<br>velocity |
|-----------------------------------|-----------------------------------|------------------------------|---|--|---|-----------------------------------|
| 760                               | 20.00                             | 298                          | 105                                       | 2.3  | 3.87  | 1.00                              |
| 20                                | 20.00                             | 298                          | 105                                       | 1.4  | 2.35  | 0.59                              |
| 20                                | 3.00                              | 298                          | 61  | 6  | 13.23   | 0.45                              |
| 3                                 | 0.01                              | 298                          | 12  | 43.6   | 217.14  | 0.39                              |
| 760                               | 0.01                              |                              |   |  | 236.59  |                                   |

Venting the bus and waveguide gas from 760 to 0.01 Torr would take less than 237 seconds (less than 4 minutes) in the worst condition, i.e., the gas is at adiabatic expansion temperature. In reality there is heat transfer between the vent gas and its surrounding hardware which are maintained around 298 °K.

With JPL's analysis results adjusted for worst conditions, there is sufficient margin to support TWTA activation approximately 55 minutes after launch.


## 7.5 Materials Outgassing Considerations

### 7.5.1 Materials TDT contribution to DAWN Outgassing Concerns

#### *Composite Materials*

There are no exceptional issues when considering the polymer matrix composite materials (carbon fiber/Cyanate ester resin) contributing additional or previously unrealized off gas products. The offgas analysis is conservative in that the analysis intentionally limited the ports for venting vent and then added additional moisture (1000 mL). These considerations significantly constrained the analysis and added conservatism.

An item not discussed with JPL or OSC is offered for the record. This problem has occurred previously and is documented by JPL in [ref. 8]: Public Lessons Learned Entry: 0404

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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>25 of 36    |

**Lesson Information:**

- Lesson Number: 0404
- Lesson Date: 1996-04-26
- Submitting Organization: JPL
- Submitted by: J.A. Roberts

**Subject:** Traveling Wave Tube Amplifier on Martian Surface: Failure Due to Corona (1976)

**Abstract:**


*“When commanded to switch on, TWTA No. 1 on Viking Lander 2 failed to produce an S-band RF downlink, probably due to RF breakdown of the high-voltage power converter. High-voltage circuits designed to operate within the Martian atmosphere require special design precautions, such as insulation from ground potential, to avoid corona or other forms of high-voltage breakdown.”*

The primary source of offgas products is moisture adsorbed onto the spacecraft bus. Initial concerns focused on the PMC as the primary adsorbed site. This is a typical concern of several PMC systems such as epoxy or polyimide resin based carbon, glass or Kevlar<sup>®</sup> fiber composites. However, cyanate ester resins off-gas and adsorb moisture very little. This resin 954-3, originally from Fiberite now is sold by Hexcel<sup>®</sup>. These resins are most often chosen for satellite applications due to their dimensional stability and very low offgas characteristics. Equally as important, cyanate ester resins perform well with respect to re-adsorption of moisture.

The following paper offers details of this and the family of the Fiberite 954: cyanate ester systems [ref. 9]:

**Abstract:**


*“Cost and weight savings achieved by the use of composites (PMC) have allowed these materials to displace their metal counterparts in space applications. Epoxy matrix based carbon fiber reinforced composites, such as Fiberite 934, have been used for a number of years. Relative to these systems, cyanate esters offer a number of unique attributes such as excellent hydrophobicity and electrical properties, reduced residual stress and better microcrack resistance, and improved radiation resistance. The significant reduction in water sorption and the low response to uptake make it possible to achieve much improved dimensional stability and reduced outgassing. These features may be used to advantage in electro-optical applications in space. ICI Fiberite has developed cyanate ester based prepreg systems that are penetrating the satellite, military radome and structural aerospace markets. Features of these systems will be presented and the properties of the cyanate ester based prepreg, Fiberite 954- 3, will be compared to those of Fiberite 934.”*

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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>26 of 36    |

While it appears that most of the concern is focused on the c-fiber/cyanate ester composite spacecraft shell providing the off gas, it was noticed that the cylindrical chamber holding carbon fiber/epoxy propellant and pressurant tanks vent to areas that will induce RF corona. Yet, the off gas analysis(es) did not account for these PMC structures. It is recommended that JPL account for the surface area of these composite overwrap pressure vessels (COPVs) as possible source of adsorbed moisture for future analyses. For this consultation, the analyses were very conservative, as mentioned above and readdressing the surface area provided by the COPVs is unnecessary.

### ***Vent Materials***

The vent holes are covered in Spectra Mesh<sup>®</sup> filter. Spectra Mesh<sup>®</sup> can be stainless steel, nylon or polypropylene. If the version of Spectra Mesh<sup>®</sup> is a breathable nylon film, then this material can absorb moisture and induce swell. The swelling could reduce pore size and alter the offgas analysis. It is also possible that the mesh/pore size is somewhat swollen at ambient conditions; then, gradually enlarges as venting proceeds. However, JPL identified Spectra Mesh<sup>®</sup> filter as a fluorocarbon film which does not absorb moisture.

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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>27 of 36    |

## 8.0 Findings, Observations, and Recommendations

### 8.1 Findings

- F-1 JPL has conducted a sufficient venting analysis to  $10^{-2}$  Torr (pending verification of assumptions for configuration and temperature).
- F-2 Although outgassing analysis was considered by JPL and OSC for the spacecraft structure, the analysis does not account for adsorbed moisture onto composite overwrapped pressure vessels.
- F-3 Based on the JPL analysis, the proposed DAWN spacecraft TWTA activation time (launch plus ~55 minutes) has sufficient margin to avoid corona.
- F-4 Venting analysis results at pressures below  $10^{-3}$  Torr may be questionable, however these are not relevant to RF corona breakdown.


### 8.2 Observations

- O-1 Many documents comprise the outgassing analysis and generated an added complexity to the real time independent review.
- O-2 For future missions, the activation of the communications equipment during spacecraft thermal vacuum test pump down at the appropriate safe pressure could validate the analysis and system performance.

### 8.3 Recommendations

The NESC concurs the DAWN spacecraft communication system is safe for activation consistent with JPL's planned turn-on of 55 minutes or longer after launch, provided the following four recommendations are accomplished prior to flight:

- R-1 Verify the vent holes in the diplexer and waveguide near the diplexer are clear of blockage.
- R-2 Review the venting analysis to ensure the gas temperature assumption of 298 °K is valid.
- R-3 Review the as-built configuration for any changes that could affect the venting analysis.
- R-4 Confirm the composition and pore size of the Spectro Mesh<sup>®</sup> filters to ensure that water droplets will pass through freely.

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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>28 of 36    |

## 9.0 Alternate Viewpoints

There were no alternate viewpoints expressed during this assessment.


## 10.0 Other Deliverables

There were no other deliverables for this assessment.

## 11.0 Lessons Learned


The activation of the communications equipment during spacecraft thermal vacuum testing at the appropriate pressure during the pump-down phase is recommended to provide validation of the venting and offgassing analyses and to ensure system performance. The communications equipment activation should not occur until the pressure has lowered to the point where corona (if applicable) will not occur for the specific system design (waveguide, diplexer, circulator, isolator), but prior to high vacuum, consistent with the planned in-flight pressure regime expected at activation.




|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>29 of 36    |

## 12.0 Definition of Terms

|                    |  |
|--------------------|--|
| Circulator         | See Isolator.  |
| Corona             | Corona is caused by electrons torn out of atoms of a gas by a strong electric field causing a current to flow in the gas.  |
| Corrective Actions | Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or material that result in preventing, minimizing, or limiting the potential for recurrence of a problem.  |
| Diplexer           | A device that combines or separates signals.   |
| Finding            | A conclusion based on facts established during the assessment/inspection by the investigating authority.   |
| Isolator           | A device to protect an amplifier from reflected power.   |
| Lessons Learned    | Knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. A lesson must be significant in that it has real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or limits the potential for failures and mishaps, or reinforces a positive result. |
| Multipactoring     | Resonant effect caused by electrons accelerating due to an electric field in a vacuum and colliding with a metal surface with enough energy to cause the emission of secondary electrons.  |
| Observation        | A factor, event, or circumstance identified during the assessment/inspection that did not contribute to the problem, but if left uncorrected has the potential to cause a mishap, injury, or increase the severity should a mishap occur.  |
| Problem            | The subject of the independent technical assessment/inspection.  |

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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>30 of 36    |

|                |  |
|----------------|--|
| Recommendation | An action identified by the assessment/inspection Team to correct a root cause or deficiency identified during the investigation. The recommendations may be used by the responsible C/P/P/O in the preparation of a corrective action plan. |
| Root Cause     | Along a chain of events leading to a mishap or close call, the first causal action or failure to act that could have been controlled systemically either by policy/practice/procedure or individual adherence to policy/practice/procedure.  |
| TWTA           | Traveling Wave Tube Amplifier, Amplifier used for high frequency microwave.  |
| X-Band         | Frequency band in the 8 GHz range.   |


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|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>31 of 36    |

## 13.0 List of Acronyms


|        |   |
|--------|---|
| EPC    | Electronic Power Converter              |
| CM     | Centimeter                              |
| COPV   | Composite Overwrap Pressure Vessels     |
| DC     | Direct Current                          |
| DI     | Deep Impact                             |
| DSN    | Deep Space Network                      |
| KV     | Kilo Volt                               |
| MM     | Millimeter                              |
| MRO    | Mars Orbiter                            |
| NRB    | NESC Review Board                       |
| OSC    | Orbital Sciences Corporation            |
| RF     | Radio Frequency                         |
| STEREO | Solar TERrestrial RELations Observatory |
| TDT    | Technical Discipline Team               |
| TV     | Thermal Vacuum                          |
| TWTA   | Traveling Wave Tube Amplifier           |
| WTS    | Waveguide Transfer Switch               |

## 14.0 References

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2. Archer, Eric. D.; "DAWN RF Component Breakdown and Waveguide Venting Discussion," June 30, 2004
3. Woo, R.; "Final Report on RF Voltage Breakdown in Coaxial Transmission Lines," JPL Technical Report 32-1500, October 1, 1970
4. Ganapathi, Gani and Archer, Eric. D.; "Bus and Waveguide Venting Analysis Status," September 1, 2004
5. Ganapathi, Gani; "Waveguide Analysis," August 25, 2004
6. Ganapathi, Gani; "Analysis Extended to Include Outgassing Effects," March 15, 2005
7. Ganapathi, Gani; "DAWN Bus Venting" May 12, 2006


|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br>32 of 36    |

8. Roberts, J.A., Traveling Wave Tube Amplifier on Martian Surface: Failure Due to Corona, Public Lessons Learned Entry: 0404 ,1976
9. Almen, G. R.; MacKenzie, P. D.; Malhotra, Vinay; Maskell, R. K., Fiberite 954: cyanate ester systems, Proc. SPIE Vol. 1690, p. 288-299, Design of Optical Instruments, 1992

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|---|--|--------------------------------|----------------------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b>     |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</b>       |  |                                | Page #:<br><b>33 of 36</b> |


## Volume II: Appendices

- A. NESC Request Form (NESC-PR-003-FM-01)


|   |  |                 |            |
|---|--|-----------------|------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:     | Version:   |
|   |  | <b>RP-07-49</b> | <b>1.0</b> |
| Title:  |  | Page #:         |            |
| DAWN Mission Bus and Waveguide Venting Analysis Review                            |  | 34 of 36        |            |

## Appendix A. NESC Request Form NESC-PR-003-FM-01

| NASA Engineering and Safety Center<br>Request Form   |                                       |                       |
|--|---------------------------------------|-----------------------|
| Submit this ITA/I Request, with associated artifacts attached, to: <a href="mailto:nrbexecsec@nasa.gov">nrbexecsec@nasa.gov</a> , or to NRB Executive Secretary, M/S 105, NASA Langley Research Center, Hampton, VA 23681  |                                       |                       |
| <b>Section 1: NESC Review Board (NRB) Executive Secretary Record of Receipt</b>  |                                       |                       |
| Received (mm/dd/yyyy h:mm am/pm)<br>5/2/2007 12:00 AM  | Status: New                           | Reference #: 07-022-E |
| Initiator Name: Lloyd Keith  | E-mail:<br>R.Lloyd.Keith@jpl.nasa.gov | Center: JPL           |
| Phone: ( )- - , Ext  | Mail Stop:                            |                       |
| Short Title: DAWN Waveguide Venting Analysis Review  |                                       |                       |
| <p>Description:</p> <p>The DAWN project did an analysis that concluded that the TWTA can be turned on within a very short time after separation from the launch vehicle. Many satellites wait 24 hours before turning the TWTAs on (these are Earth orbiters). There is some residual concern that turning on a TWTA without waiting 24 hours could cause a failure due to insufficient venting of gasses from the chambers. The fault protection as currently set would immediately turn the spare TWTA on potential causing the same type of failure and ending the mission (no comms).</p> <p>The request is for a quick reaction independent review of the Dawn waveguide venting analysis performed by JPL (information provided by Lloyd Keith on May 2, 2007). The issue relates to the amount of time after launch that is needed to wait before the Traveling Wave Tube Assembly (TWTA) can be powered on without the threat of high voltage/RF breakdown and possible damage due to partial pressure. Preliminary findings, observations, and recommendations are requested by May 11, 2007 and a final report by May 25, 2007. The DAWN project did an analysis that concluded that the TWTA can be turned on within a very short time after separation from the launch vehicle. Many satellites wait 24 hours before turning the TWTAs on (these are Earth orbiters). There is some residual concern that turning on a TWTA without waiting 24 hours could cause a failure due to insufficient venting of gasses from the chambers. The fault protection as currently set would immediately turn the spare TWTA on potential causing the same type of failure and ending the mission (no comms).</p> <p>The project has asked NESC to independently review the analysis to verify the assumptions and calculations. The DAWN launch is scheduled for June 2007, so any inputs will have to be provided very quickly.</p> |                                       |                       |
| Source (e.g. email, phone call, posted on web): undetermined   |                                       |                       |
| Type of Request: Support   |                                       |                       |
| Proposed Need Date:  |                                       |                       |
| Date forwarded to Systems Engineering Office (SEO): (mm/dd/yyyy h:mm am/pm):   |                                       |                       |
| <b>Section 2: Systems Engineering Office Screening</b>   |                                       |                       |
| <b>Section 2.1 Potential ITA/I Identification</b>  |                                       |                       |

|   |  |                     |            |
|---|--|---------------------|------------|
|  | <b>NASA Engineering and Safety Center<br/>Technical Report</b> | Document #:         | Version:   |
|   |  | <b>RP-07-49</b>     | <b>1.0</b> |
| Title:<br><b>DAWN Mission Bus and Waveguide Venting Analysis Review</b>           |  | Page #:<br>35 of 36 |            |

|   |                |                      |
|---|----------------|----------------------|
| Received by SEO: (mm/dd/yyyy h:mm am/pm): 5/3/2007 12:00 AM   |                |                      |
| Potential ITA/I candidate? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No                  |                |                      |
| Assigned Initial Evaluator (IE): Mitch Davis to provide support. Approved Out-of-Board by Ralph Roe on 5/4/2007 |                |                      |
| Date assigned (mm/dd/yyyy): 5/4/2007  |                |                      |
| Due date for ITA/I Screening (mm/dd/yyyy):  |                |                      |
| <b>Section 2.2 Non-ITA/I Action</b>   |                |                      |
| Requires additional NESC action (non-ITA/I)? <input type="checkbox"/> Yes <input type="checkbox"/> No           |                |                      |
| If yes:   |                |                      |
| Description of action:  |                |                      |
| Actionee:   |                |                      |
| Is follow-up required? <input type="checkbox"/> Yes <input type="checkbox"/> No If yes: Due Date:               |                |                      |
| Follow-up status/date:  |                |                      |
| If no:  |                |                      |
| NESC Director Concurrence (signature):  |                |                      |
| Request closure date:   |                |                      |
| <b>Section 3: Initial Evaluation</b>  |                |                      |
| Received by IE: (mm/dd/yyyy h:mm am/pm):  |                |                      |
| Screening complete date:  |                |                      |
| Valid ITA/I candidate? <input type="checkbox"/> Yes <input type="checkbox"/> No                                 |                |                      |
| Initial Evaluation Report #: NESC-PN-   |                |                      |
| Target NRB Review Date:   |                |                      |
| <b>Section 4: NRB Review and Disposition of NCE Response Report</b>   |                |                      |
| ITA/I Approved: <input type="checkbox"/> Yes <input type="checkbox"/> No  | Date Approved: | Priority: - Select - |
| ITA/I Lead: , Phone ( ) - , x   |                |                      |
| <b>Section 5: ITA/I Lead Planning, Conduct, and Reporting</b>   |                |                      |
| Plan Development Start Date:  |                |                      |
| ITA/I Plan # NESC-PL-   |                |                      |
| Plan Approval Date:   |                |                      |
| ITA/I Start Date  | Planned:       | Actual:              |
| ITA/I Completed Date:   |                |                      |
| ITA/I Final Report #: NESC-PN-  |                |                      |
| ITA/I Briefing Package #: NESC-PN-  |                |                      |
| Follow-up Required? <input type="checkbox"/> Yes <input type="checkbox"/> No                                    |                |                      |
| <b>Section 6: Follow-up</b>   |                |                      |
| Date Findings Briefed to Customer:  |                |                      |
| Follow-up Accepted: <input type="checkbox"/> Yes <input type="checkbox"/> No                                    |                |                      |
| Follow-up Completed Date:   |                |                      |
| Follow-up Report #: NESC-RP-  |                |                      |
| <b>Section 7: Disposition and Notification</b>  |                |                      |
| Notification type: - Select -   | Details:       |                      |
| Date of Notification:   |                |                      |
| Final Disposition: - Select -   |                |                      |
| Rationale for Disposition:  |                |                      |
| Close Out Review Date:  |                |                      |

|   |  |                                |                        |
|---|--|--------------------------------|------------------------|
|                          | <h1 style="text-align: center;">NASA Engineering and Safety Center<br/>Technical Report</h1> | Document #:<br><b>RP-07-49</b> | Version:<br><b>1.0</b> |
| Title:<br><h2 style="text-align: center;">DAWN Mission Bus and Waveguide Venting Analysis<br/>Review</h2> |  |                                | Page #:<br>36 of 36    |

### Form Approval and Document Revision History

|                                  |               |
|----------------------------------|---------------|
| Approved: _____<br>NESC Director | _____<br>Date |
|----------------------------------|---------------|

| Version | Description of Revision | Office of Primary Responsibility | Effective Date |
|---------|-------------------------|----------------------------------|----------------|
| 1.0     | Initial Release         | Principal Engineers Office       | 29 Jan 04      |



| REPORT DOCUMENTATION PAGE   |             |  |                               | Form Approved<br>OMB No. 0704-0188  |   |
|---|-------------|--|-------------------------------|---|---|
| <p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b></p>   |             |  |                               |   |   |
| 1. REPORT DATE (DD-MM-YYYY)<br>31-10-2007   |             | 2. REPORT TYPE<br>Technical Memorandum |                               | 3. DATES COVERED (From - To)<br>May 2007- May 2007                                |   |
| 4. TITLE AND SUBTITLE<br><br>DAWN Mission Bus and Waveguide Venting Analysis Review   |             |  |                               | 5a. CONTRACT NUMBER   |   |
|   |             |  |                               | 5b. GRANT NUMBER  |   |
|   |             |  |                               | 5c. PROGRAM ELEMENT NUMBER  |   |
| 6. AUTHOR(S)<br><br>Cragg, Clint H.; Kichak, Robert A.; Sutter, James K.; Holder, Donald; Jeng, Frank; Ruitberg, Aurthur; Sank, Victor.   |             |  |                               | 5d. PROJECT NUMBER  |   |
|   |             |  |                               | 5e. TASK NUMBER   |   |
|   |             |  |                               | 5f. WORK UNIT NUMBER<br><br>510505.01.07.01.06                                    |   |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><br>NASA Engineering and Safety Center<br>Langley Research Center<br>Hampton, VA 23681-2199   |             |  |                               | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER<br><br>L-19423 NESC-RP-07-49/07-022-E |   |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br><br>National Aeronautics and Space Administration<br>Washington, DC 20546-0001   |             |  |                               | 10. SPONSORING/MONITOR'S ACRONYM(S)<br><br>NASA                                   |   |
|   |             |  |                               | 11. SPONSORING/MONITORING<br>REPORT NUMBER<br><br>NASA/TM-2007- 215091            |   |
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| 13. SUPPLEMENTARY NOTES   |             |  |                               |   |   |
| 14. ABSTRACT<br><br>A concern was raised regarding the time after launch when the DAWN Mission Communications Subsystem, which contains a 100 Watt X-Band Traveling Wave Tube Amplifier (TWTA) with a high voltage ((approximately 7 Kilo Volt (KV)) Electronic Power Converter (EPC), will be powered on for the first post-launch downlink. This activation is planned to be approximately one hour after launch. Orbital Sciences (the DAWN Mission spacecraft contractor) typically requires a 24-hour wait period prior to high voltage initiation for Earth-orbiting Science and GEO spacecraft. The concern relates to the issue of corona and/or radio frequency (RF) breakdown of the TWTA ((high voltage direct current (DC) and RF)), and of the microwave components (high voltage RF) in the presence of partial atmospheric pressures or outgassing constituents. In particular, generally the diplexer and circulator are susceptible to RF breakdown in the corona region due to the presence of small physical gaps ((~ 2.5 millimeter (mm)) between conductors that carry an RF voltage. The NESC concurred the DAWN Mission communication system is safe for activation. |             |  |                               |   |   |
| 15. SUBJECT TERMS<br><br>NESC, DAWN, Traveling Wave Tube Amplifier (TWTA), Electronic Power Converter (EPC), Orbital Sciences Corporation (OSC), Deep Impact (DI), Solar TERrestrial Relations Observatory (STEREO), Paschen Curve, Critical Pressure Region, Deep Space Network (DSN)  |             |  |                               |   |   |
| 16. SECURITY CLASSIFICATION OF:   |             |  | 17. LIMITATION OF<br>ABSTRACT | 18. NUMBER<br>OF<br>PAGES   | 19a. NAME OF RESPONSIBLE PERSON                             |
| a. REPORT   | b. ABSTRACT | c. THIS PAGE                           |                               |   | STI Help Desk (email: help@sti.nasa.gov)                    |
| UU  | UU          | UU                                     | UU                            | 41  | 19b. TELEPHONE NUMBER (Include area code)<br>(301) 621-0390 |